



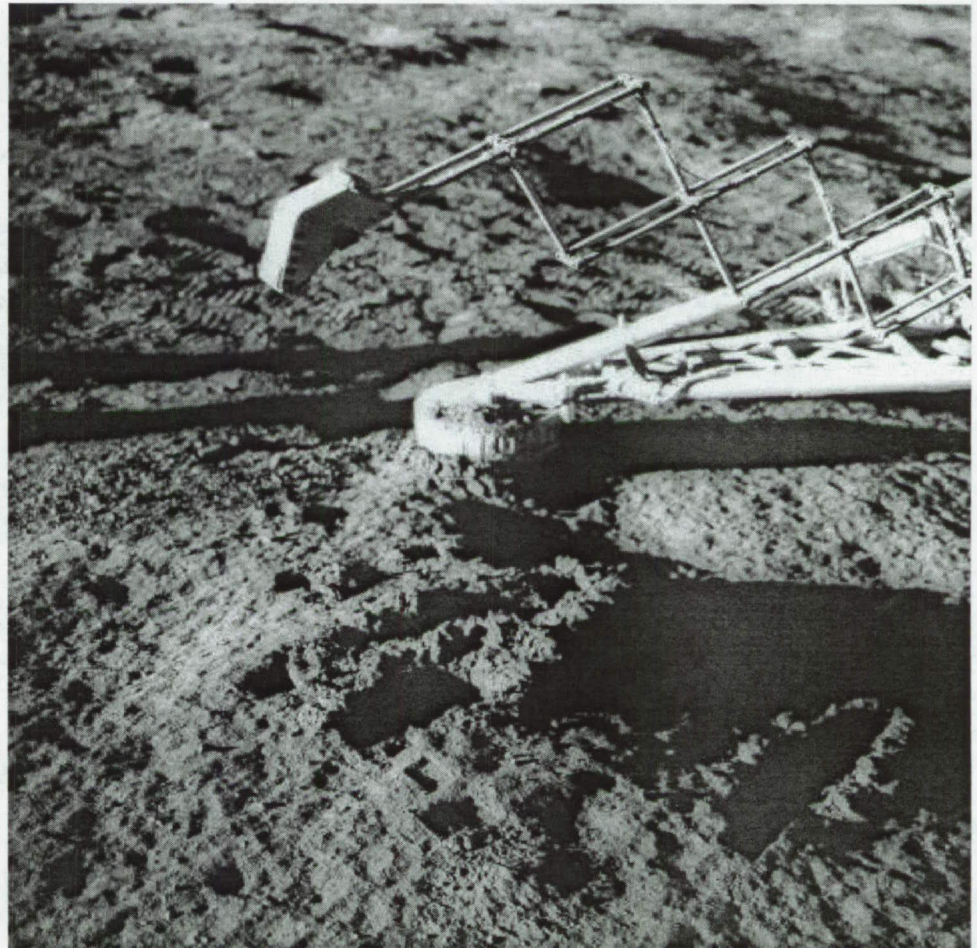
Philip Metzger, NASA
KSC Applied Physics Lab

Background

- During the Apollo and Viking programs, NASA needed to know how the rocket exhaust would affect the soil on the Moon and Mars.
- A number of studies were done during the 50's through 70's
- Existing models are crude and do not predict mass-rate or trajectories of ejected material

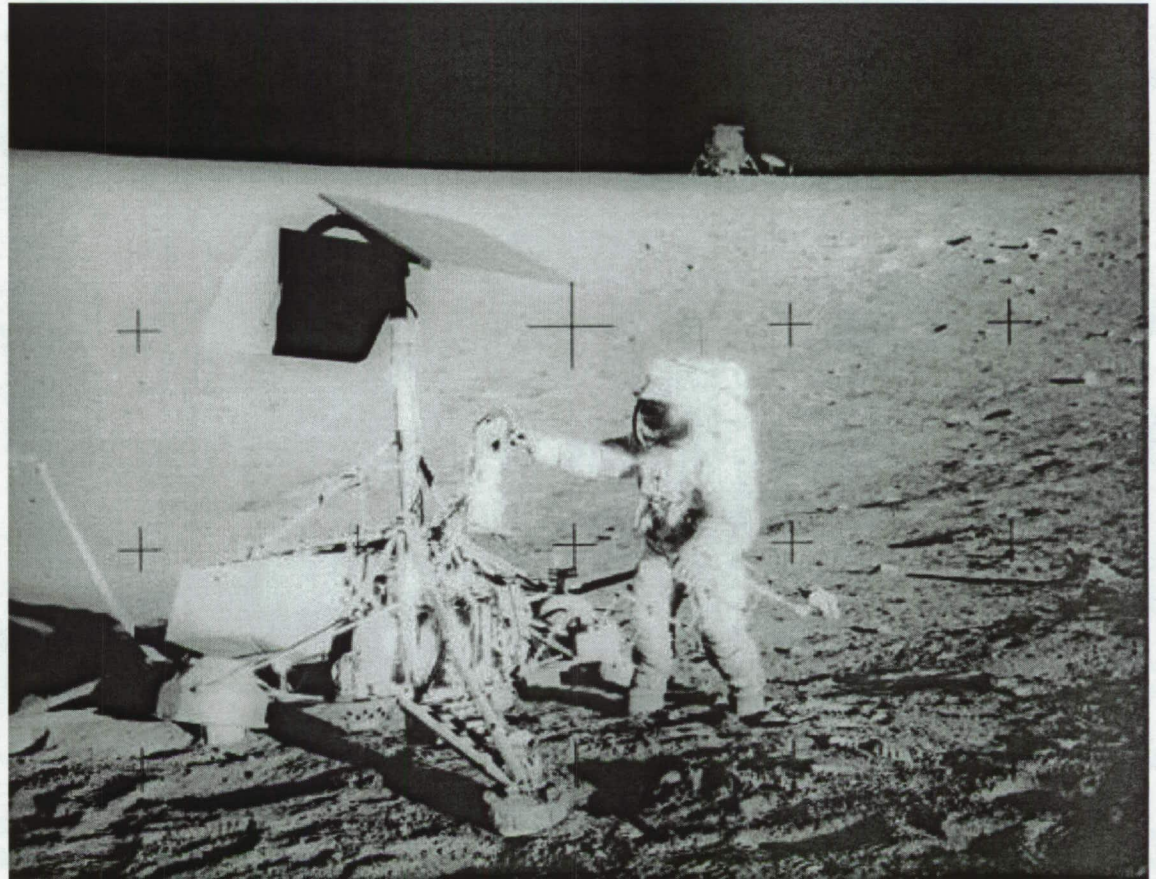
Must Protect Spacecraft from Itself

- Landing visibility
- Contamination of mechanisms
- Jamming or spoofing sensors
- Erosion of coated surfaces
- Pitting of optics



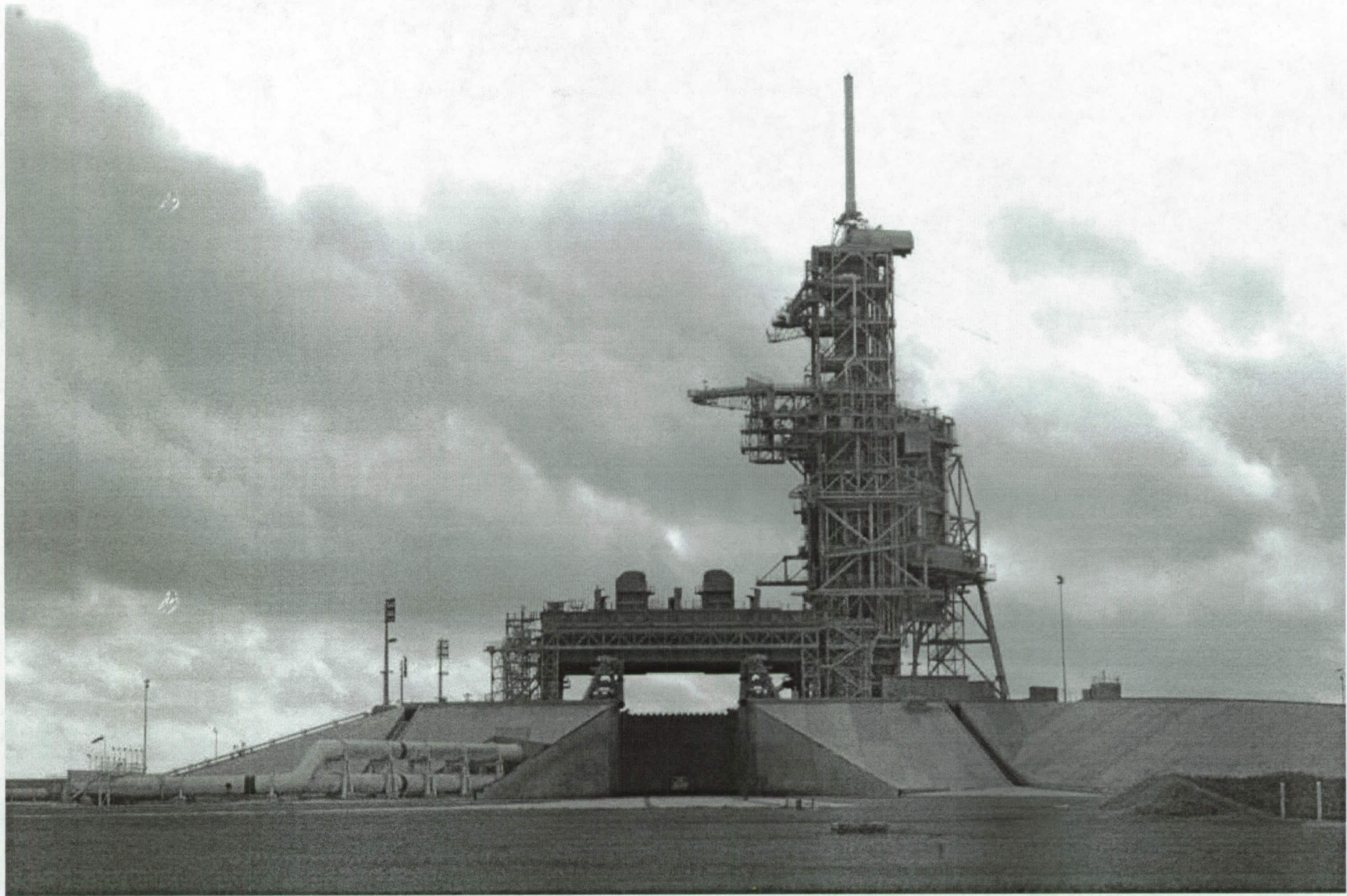
Must Protect Surrounding Hardware

- Land too close:
 - Damage
 - Contamination
 - Excessive blast hardening required
- Land too far away:
 - Excessive umbilical lengths & mass
 - Excessive travel between sites



Early Need to Validate Protective Measures

- Currently unable to specify berm height and radius
- Berm size drives excavator size and operating time
- Must specify surface asset hardening requirements in design phase



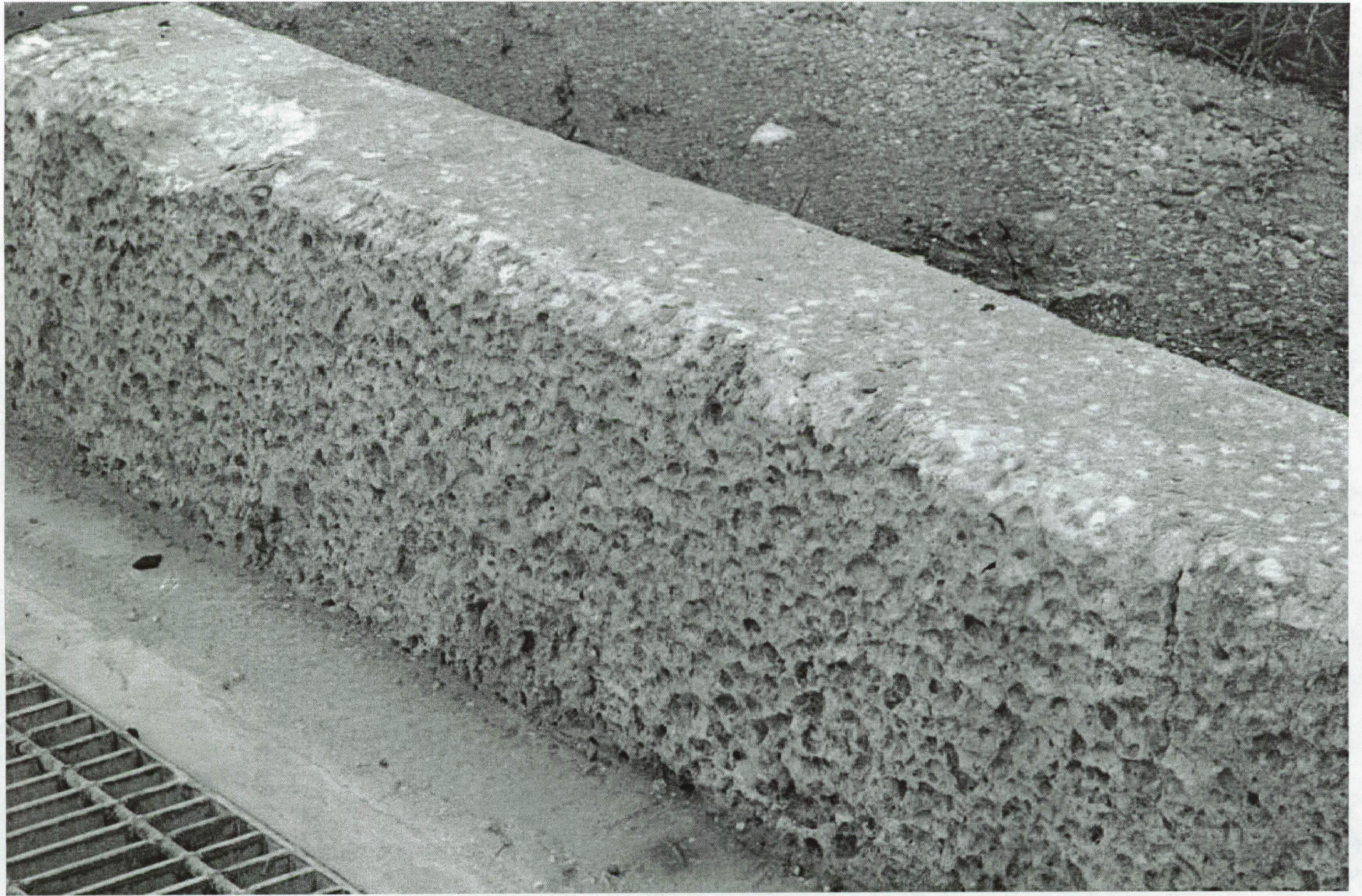


Damage to Pad perimeter fence from
chunks of martite blown out of the
flame trench







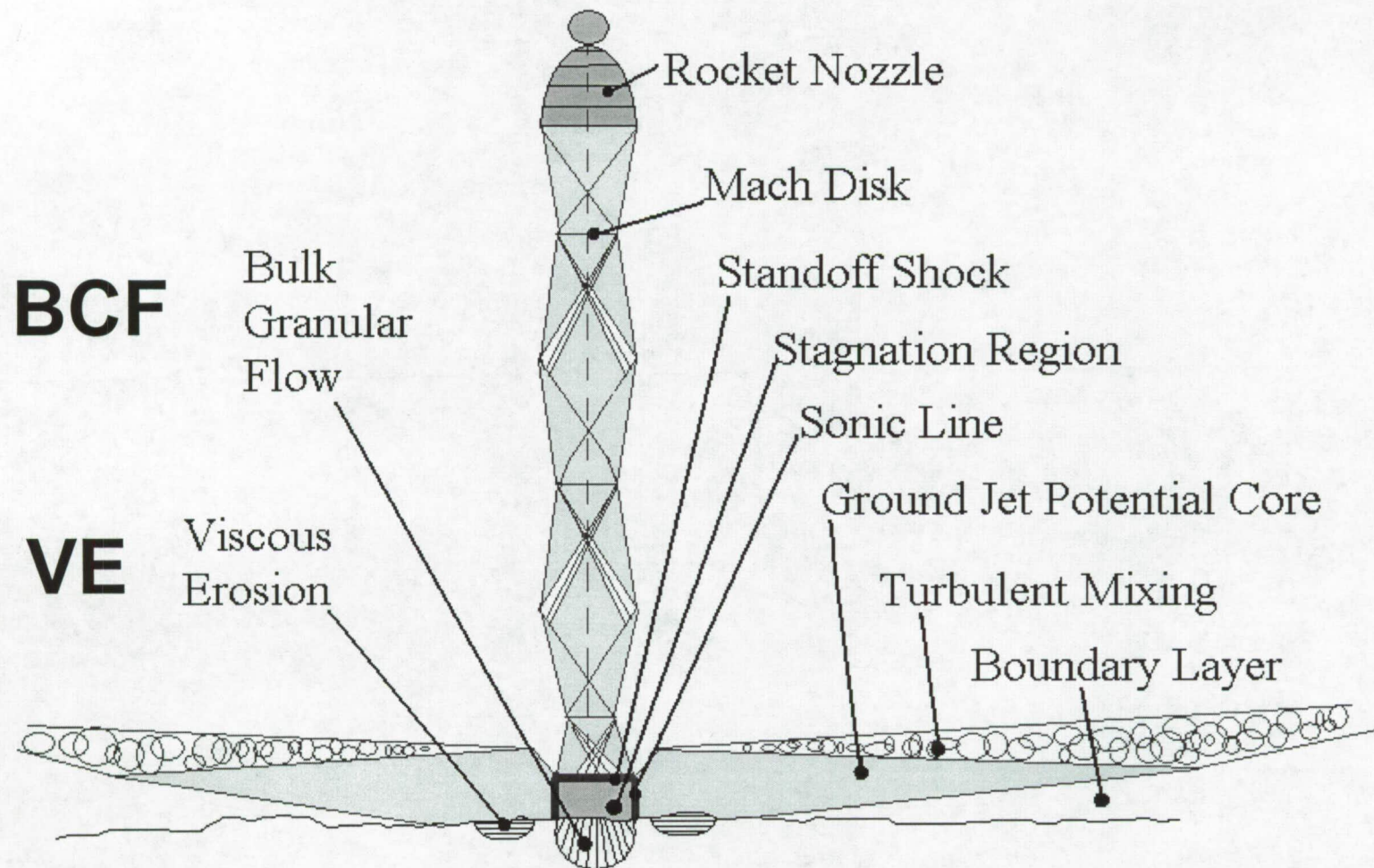


Erosion of concrete in
front of flame trench

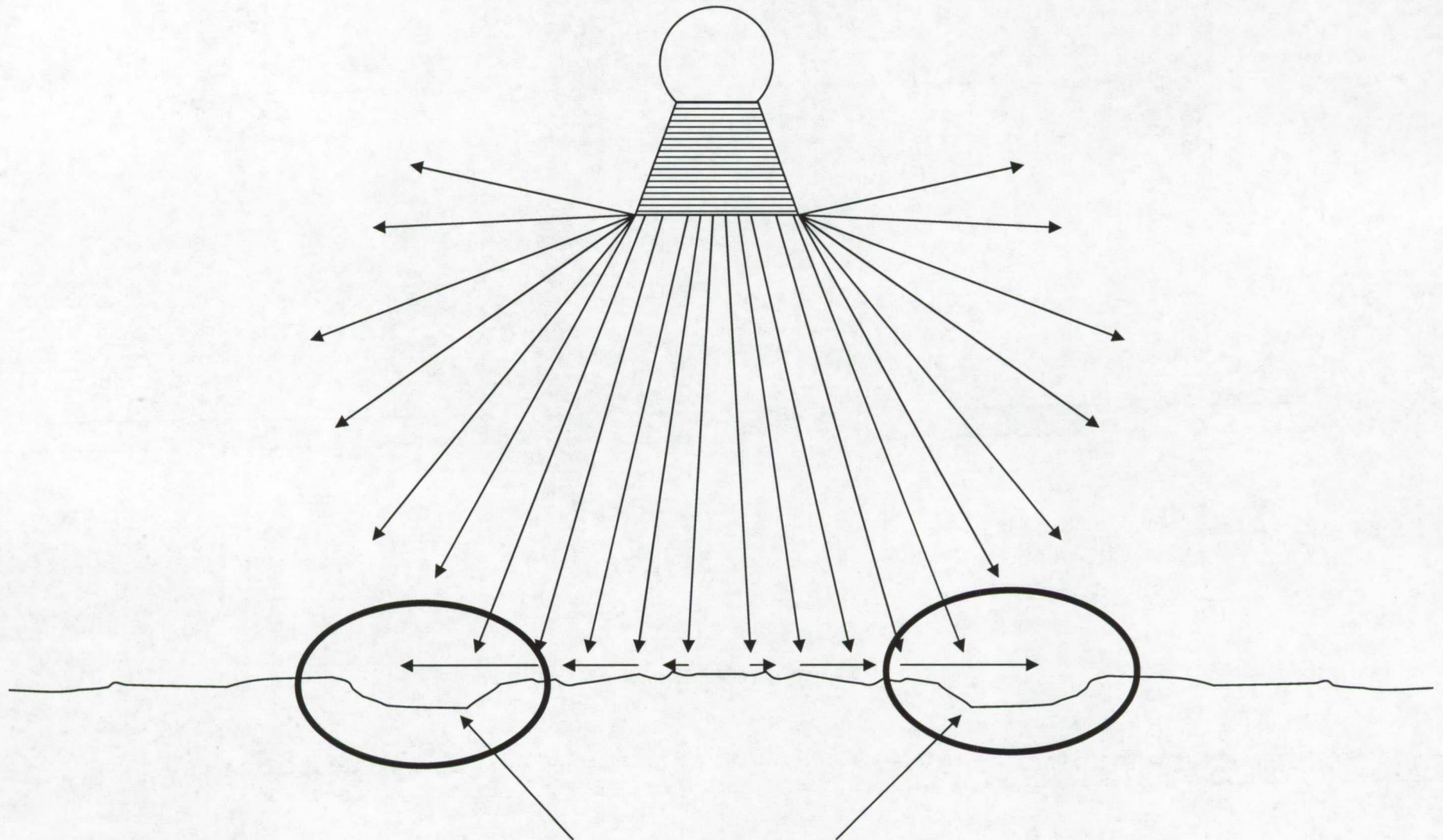


Damage to concrete wall due to
FOD caught in the launch blast

Plume / Regolith Interactions



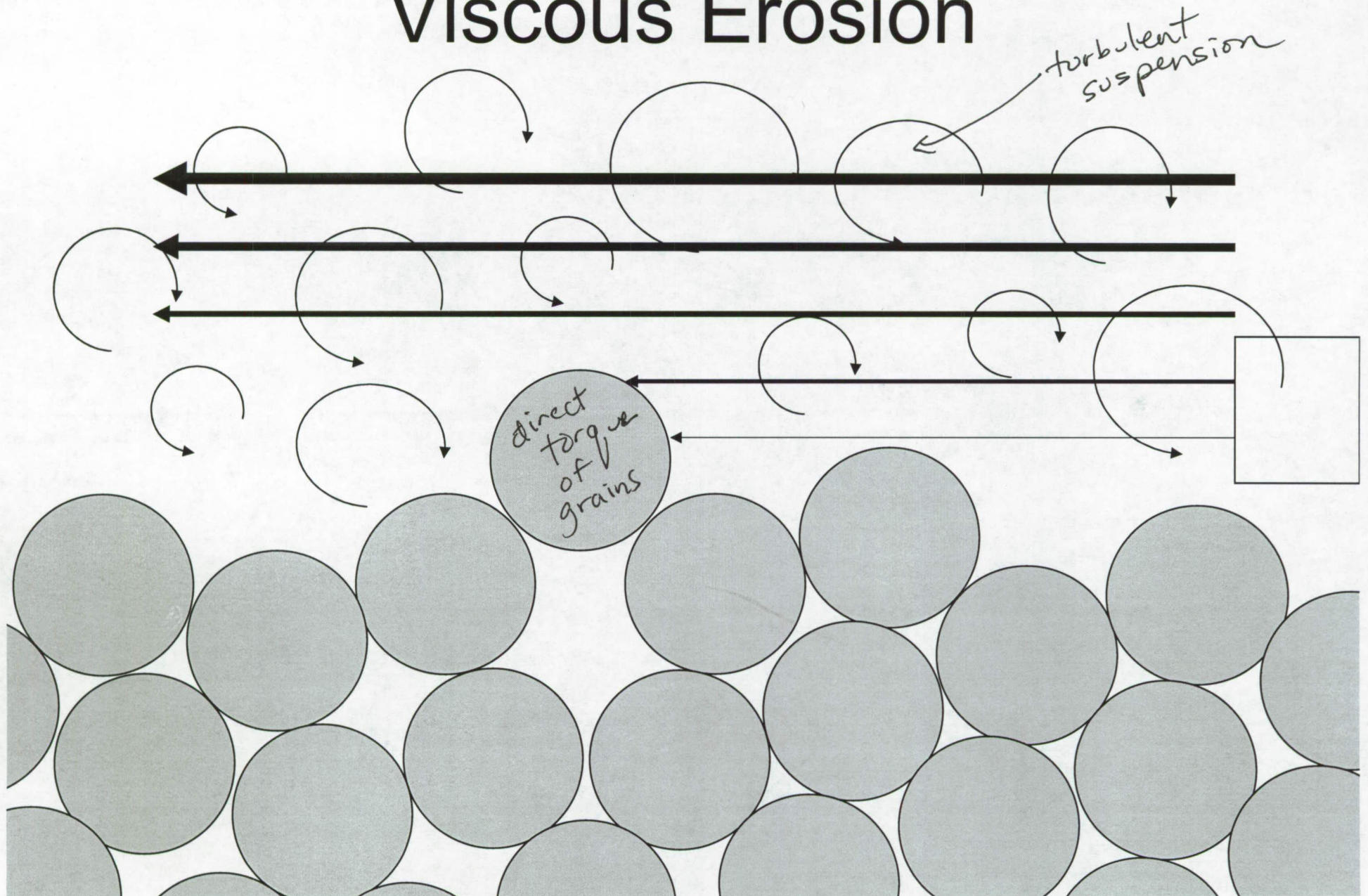
Viscous Erosion



Regions of maximum traction

Mechanisms of

Viscous Erosion

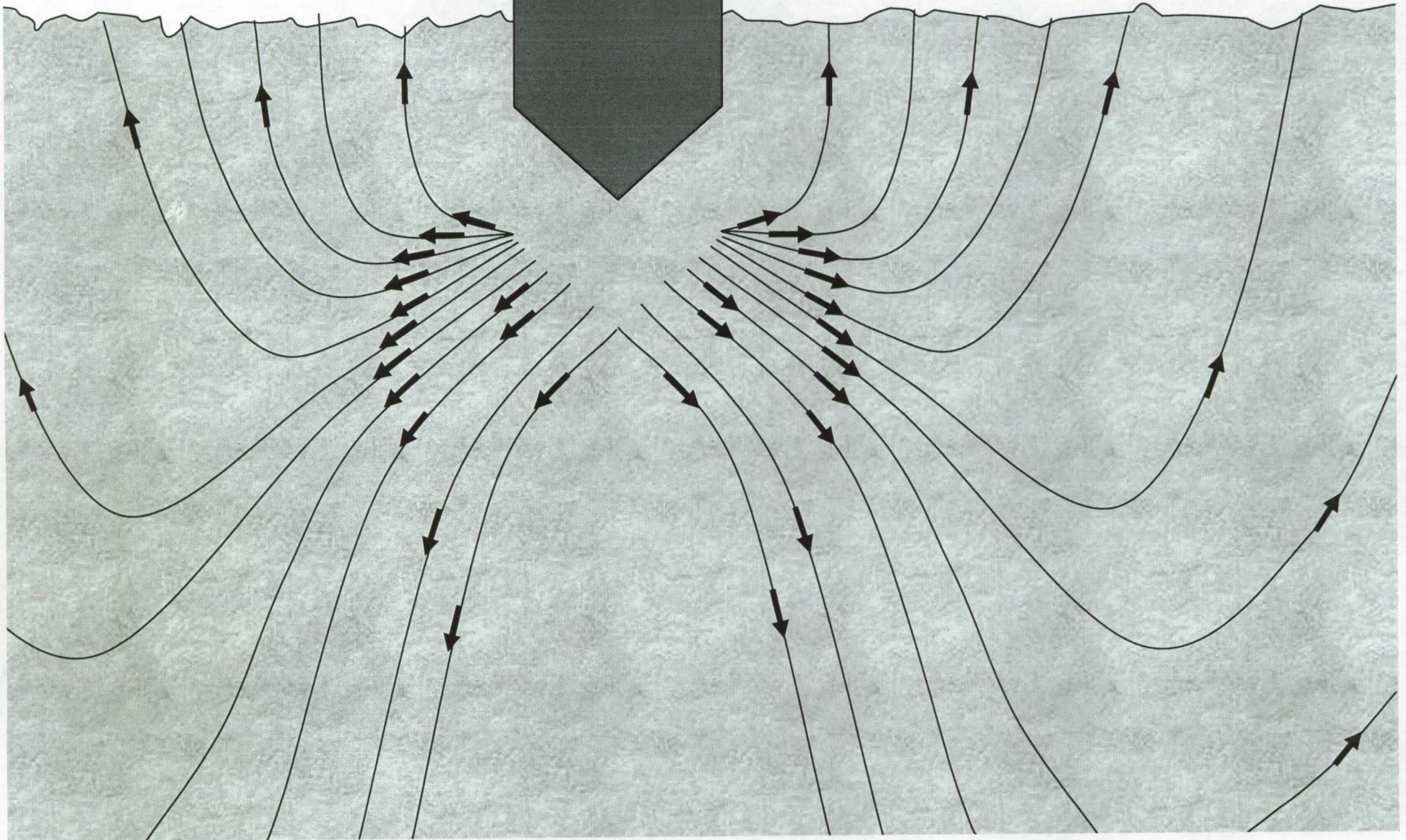


Studies of VE

- Bagnold: *The Physics of Blown Sand and Desert Dunes*
 - Fudge factors that cannot be extrapolated
 - Slow wind, terrestrial atmosphere, log-normal particle size distributions of *sand*
- Leonard Roberts
 - Assumes mechanical surface shear stress
- Experimental Work in Vacuum Chambers

well-known
Flow field during
~~Bea~~ Cone Penetration.
Assumed to be the
same for
Rocket Cratering!

After Mehmet T. Tümay,
et. al



Paradigm ca. Apollo Program

Lower Thrust

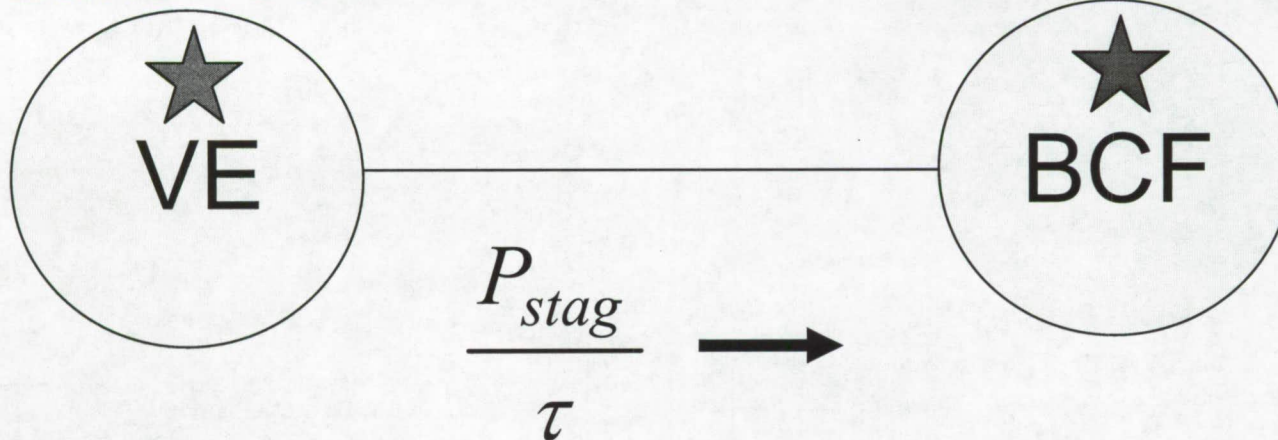
Higher Thrust

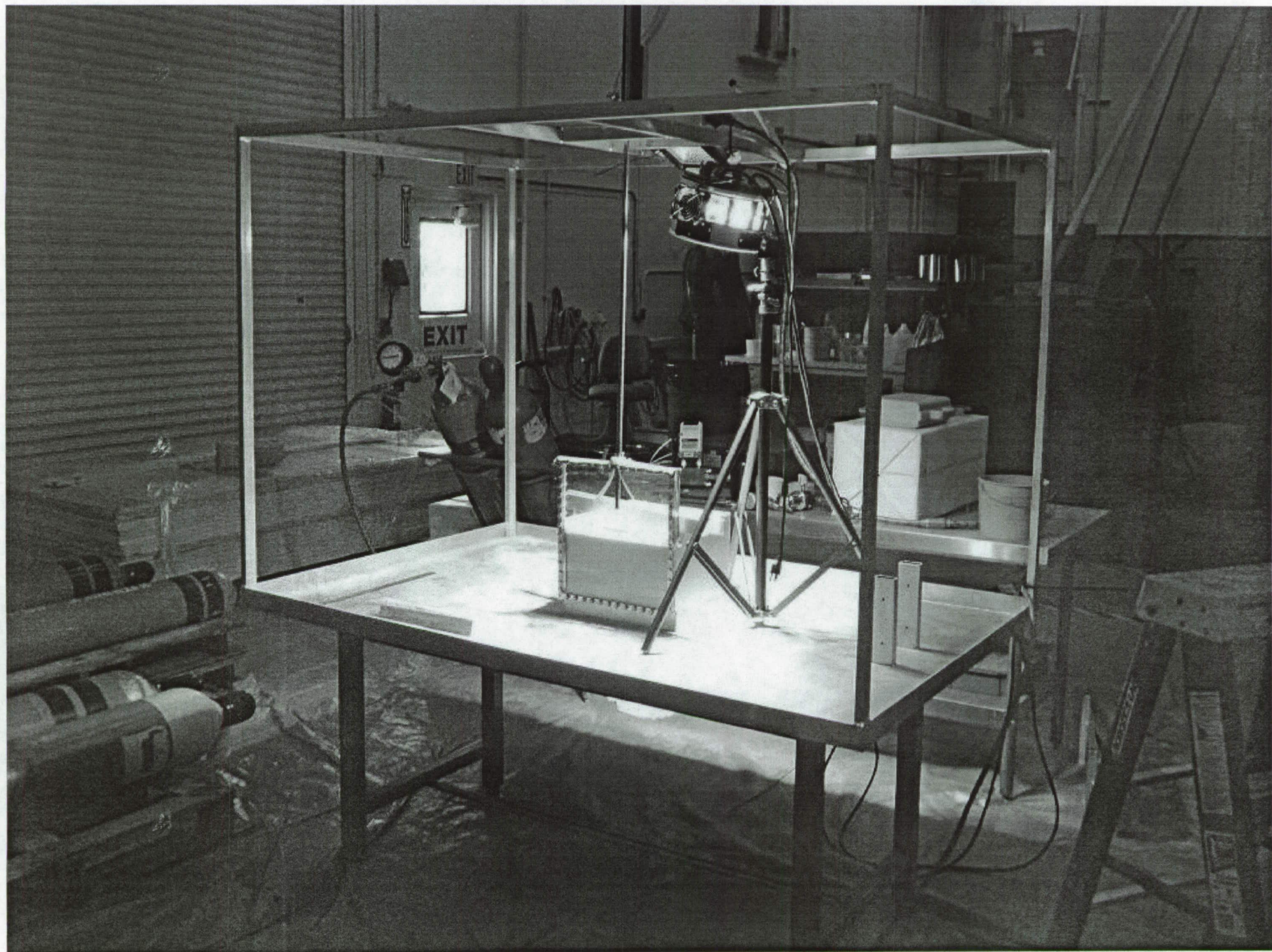
Higher Shear Strength

Lower Shear Strength

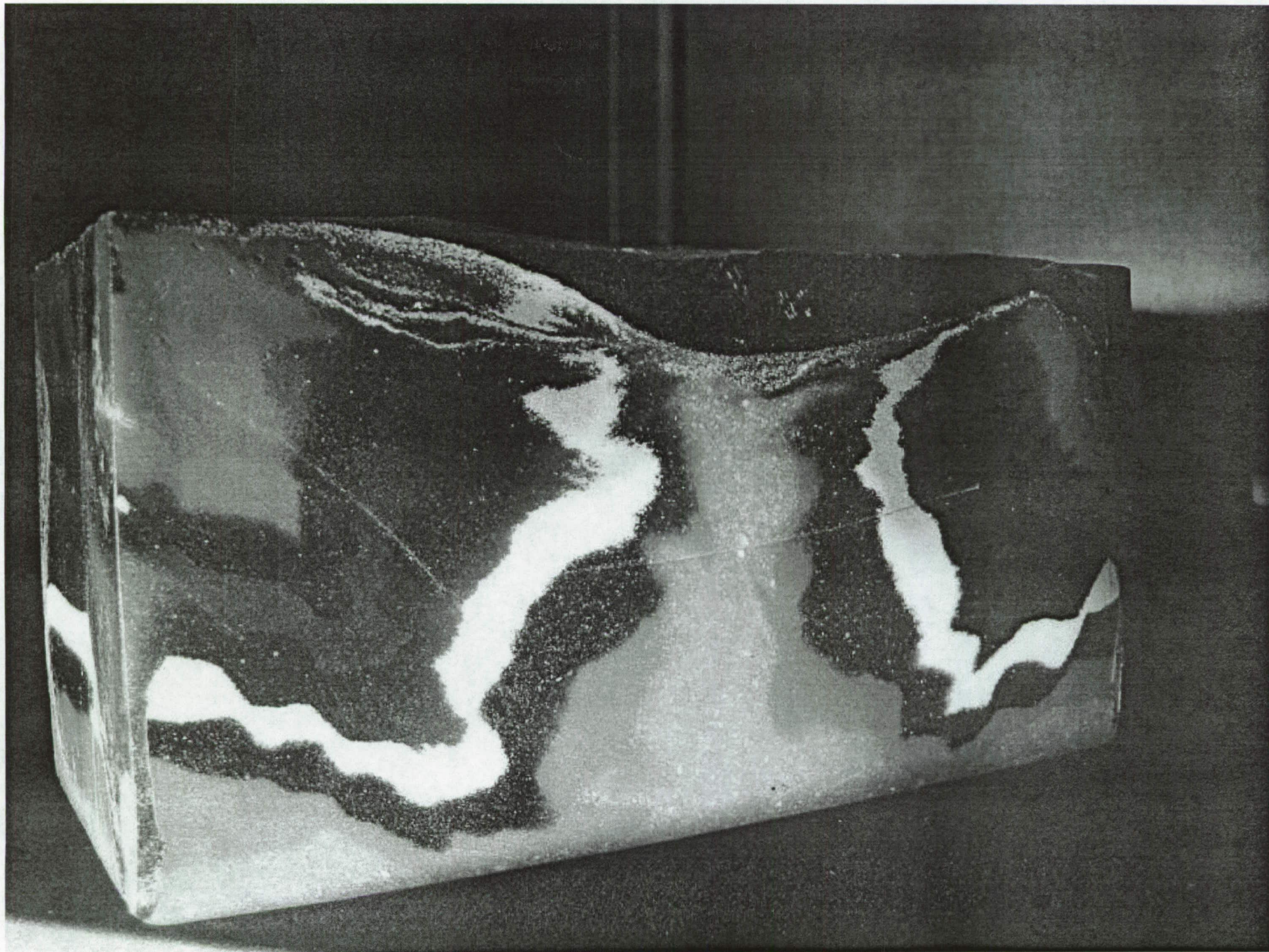
Lunar Case

Martian Case

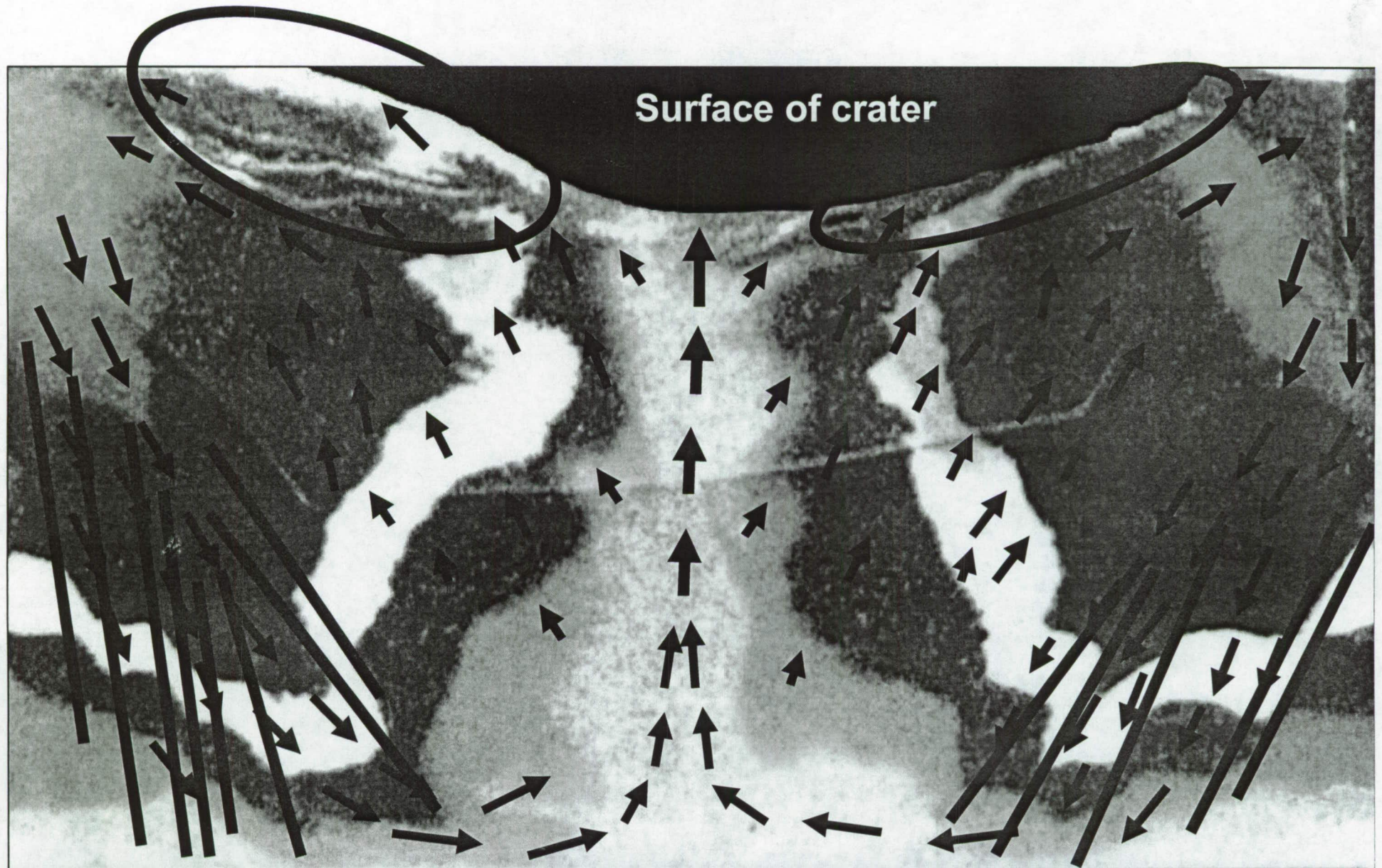




Test Setup at KSC



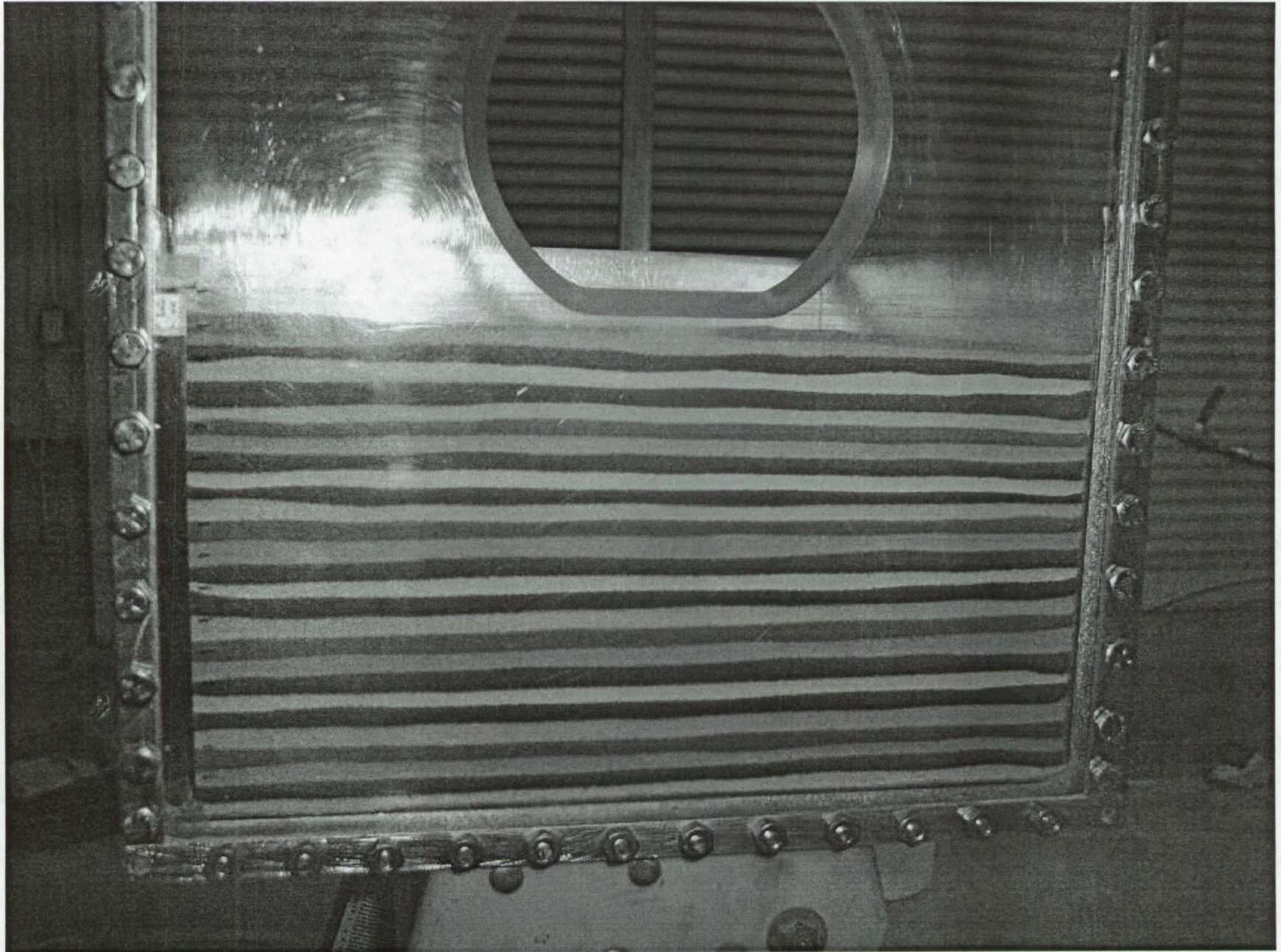
Test result → epoxied sand block



Deepest sand layer brought up through center of crater

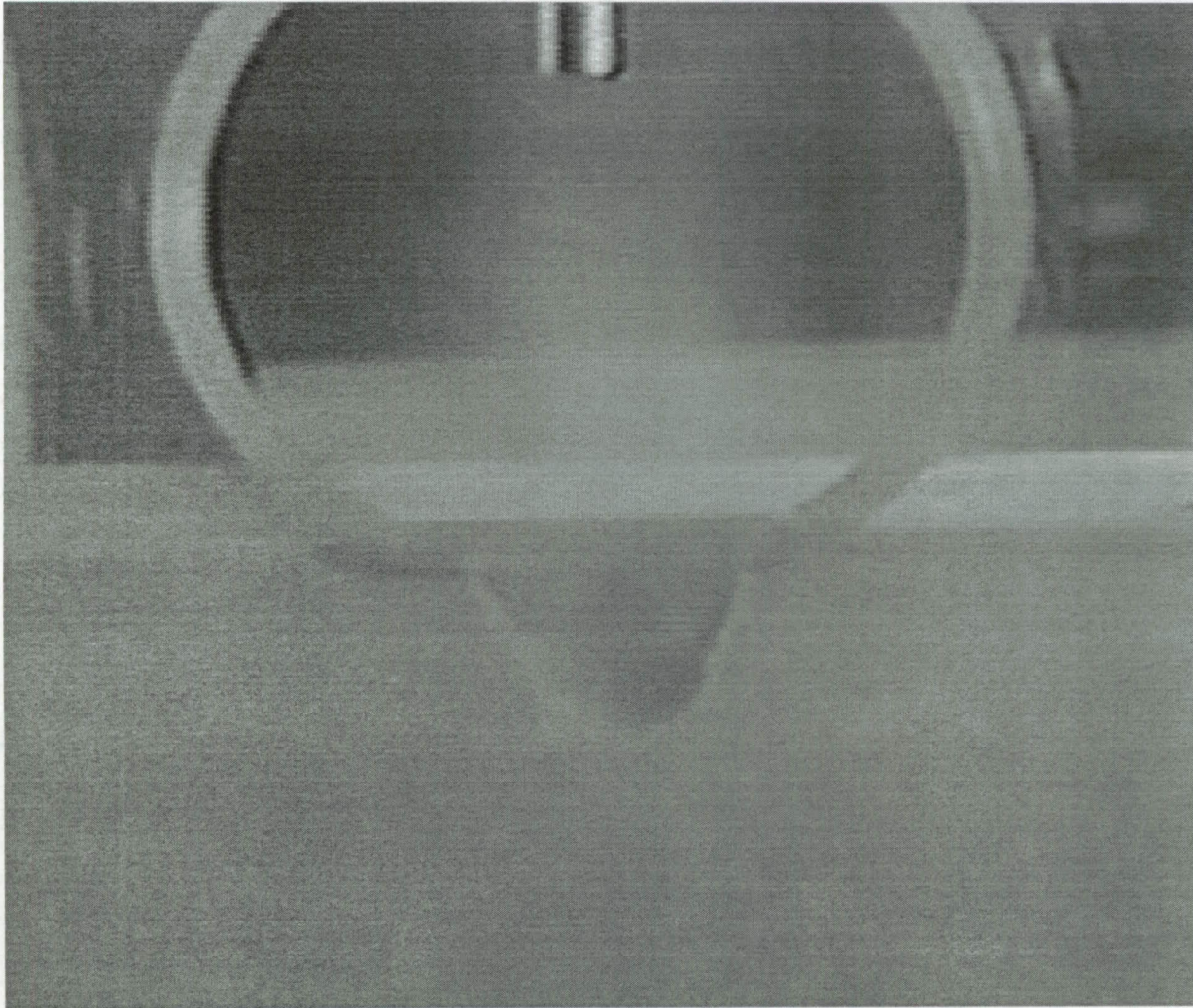
How do we explain this

Movie of deep cratering

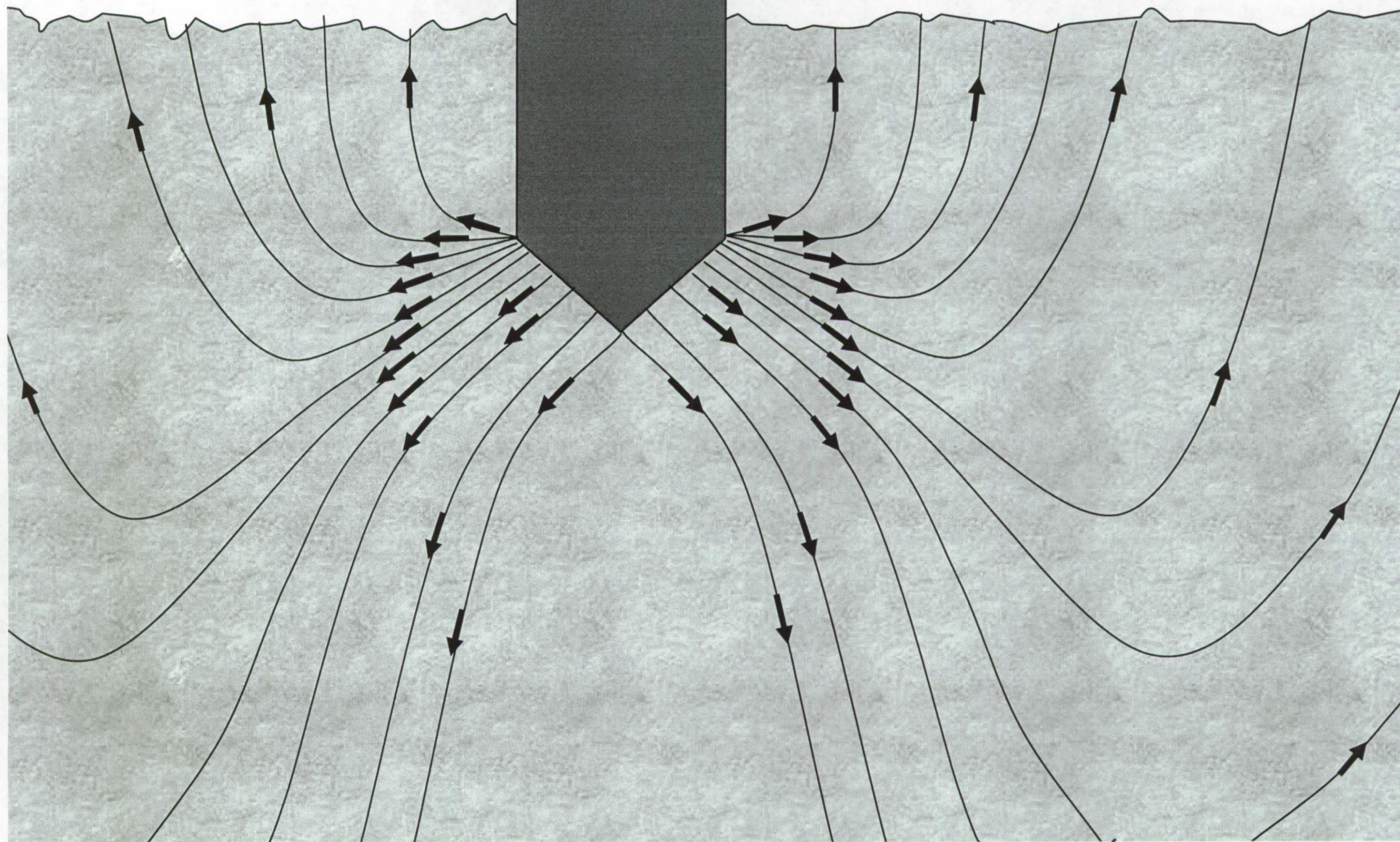


Movie showing how previous page occurs

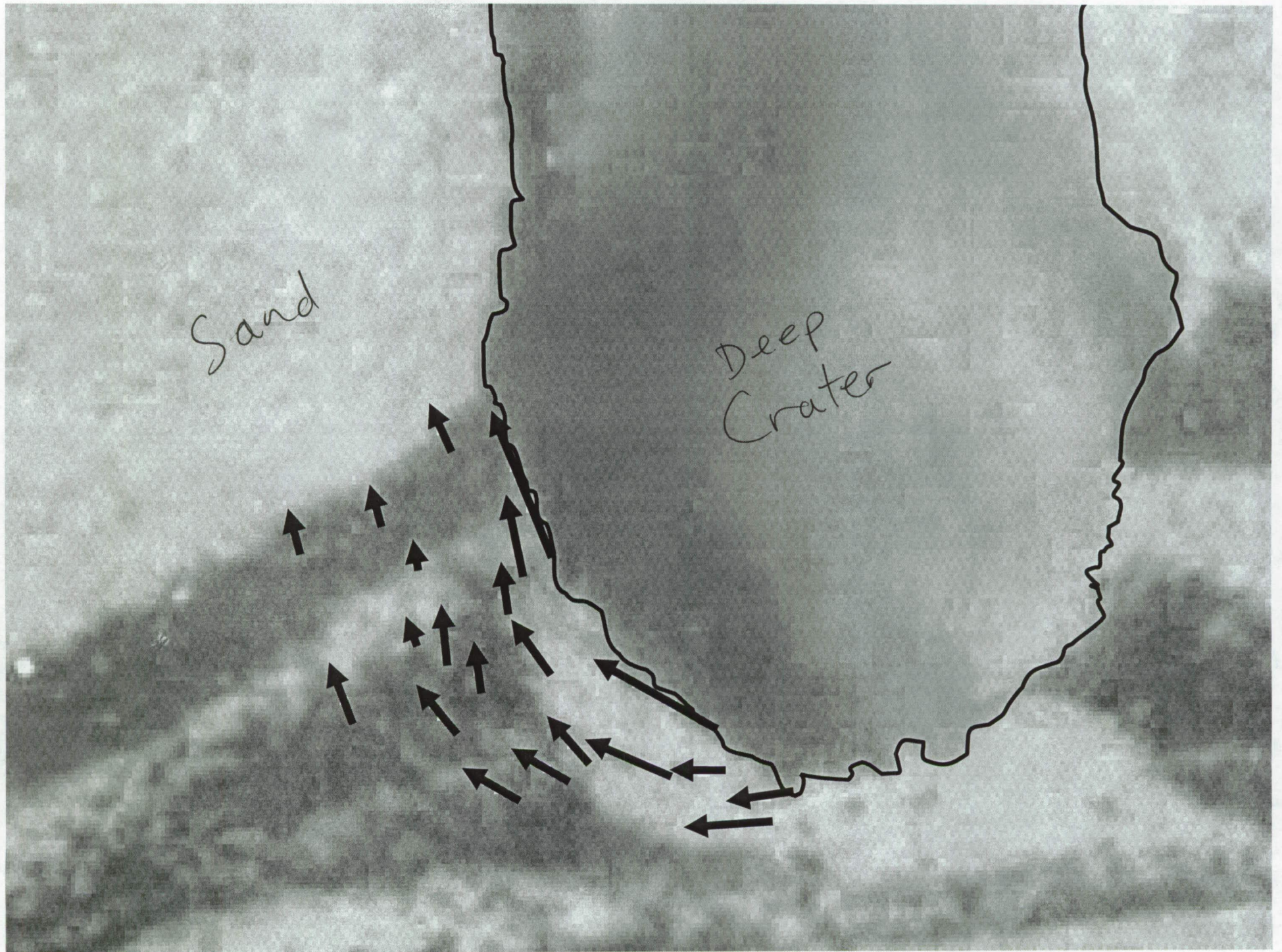
Movie of “slower” deep cratering



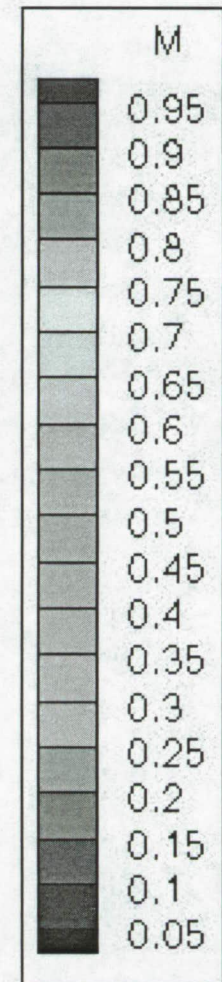
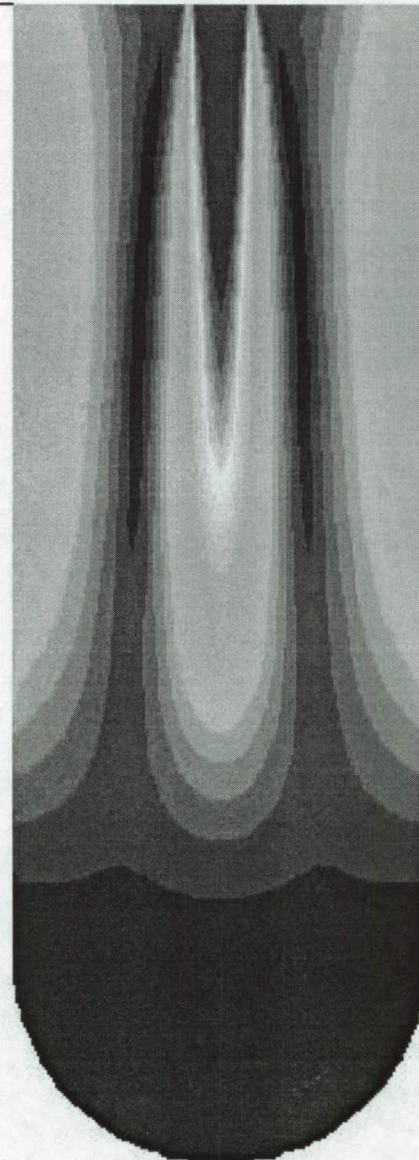
After Mehmet T. Tümay,
et. al



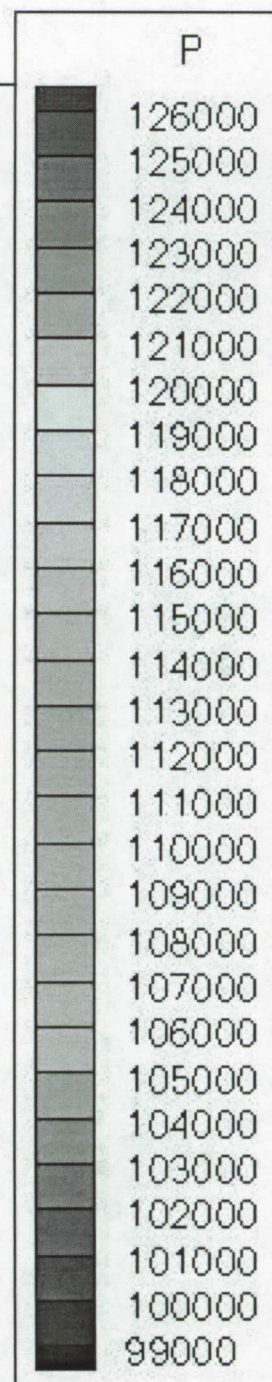
But we expected this to happen! (It did not)



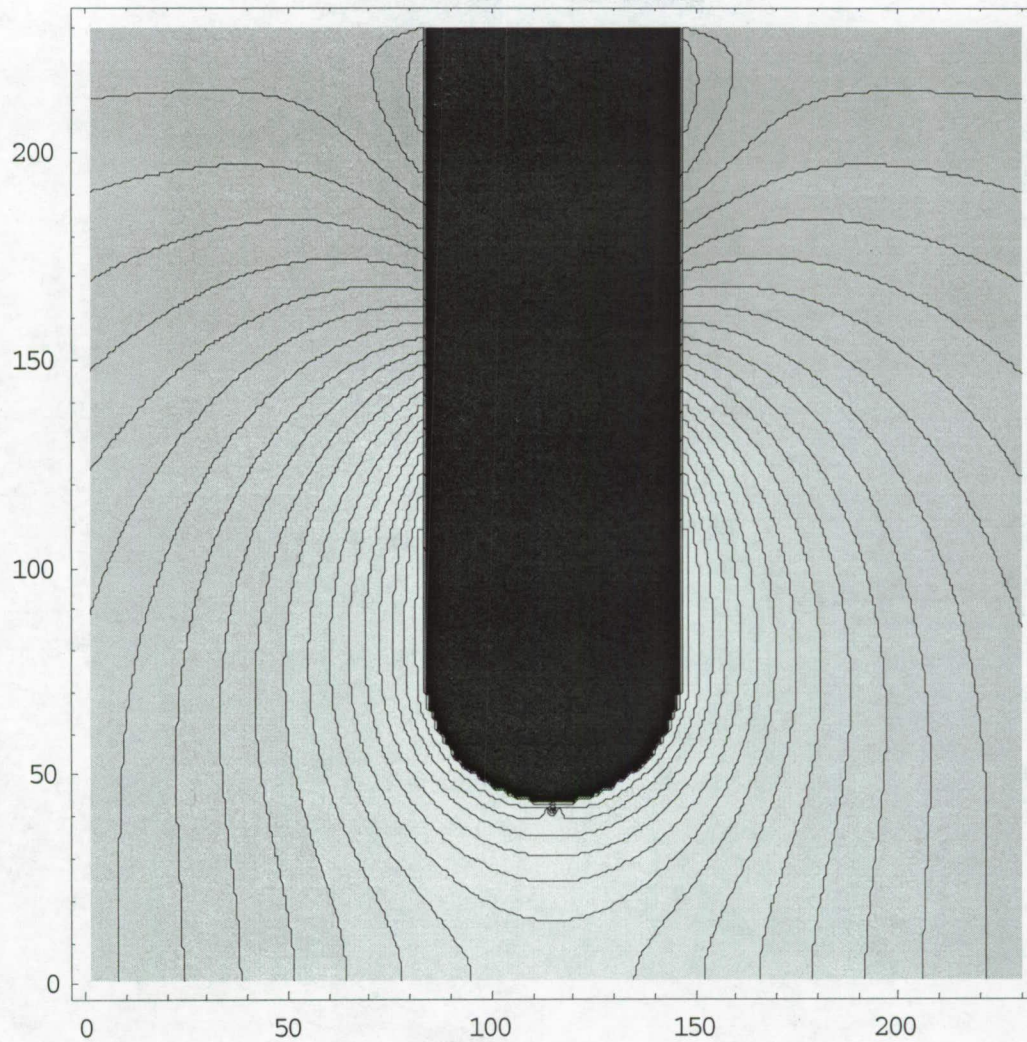
The flow is tangential to the crater! why?



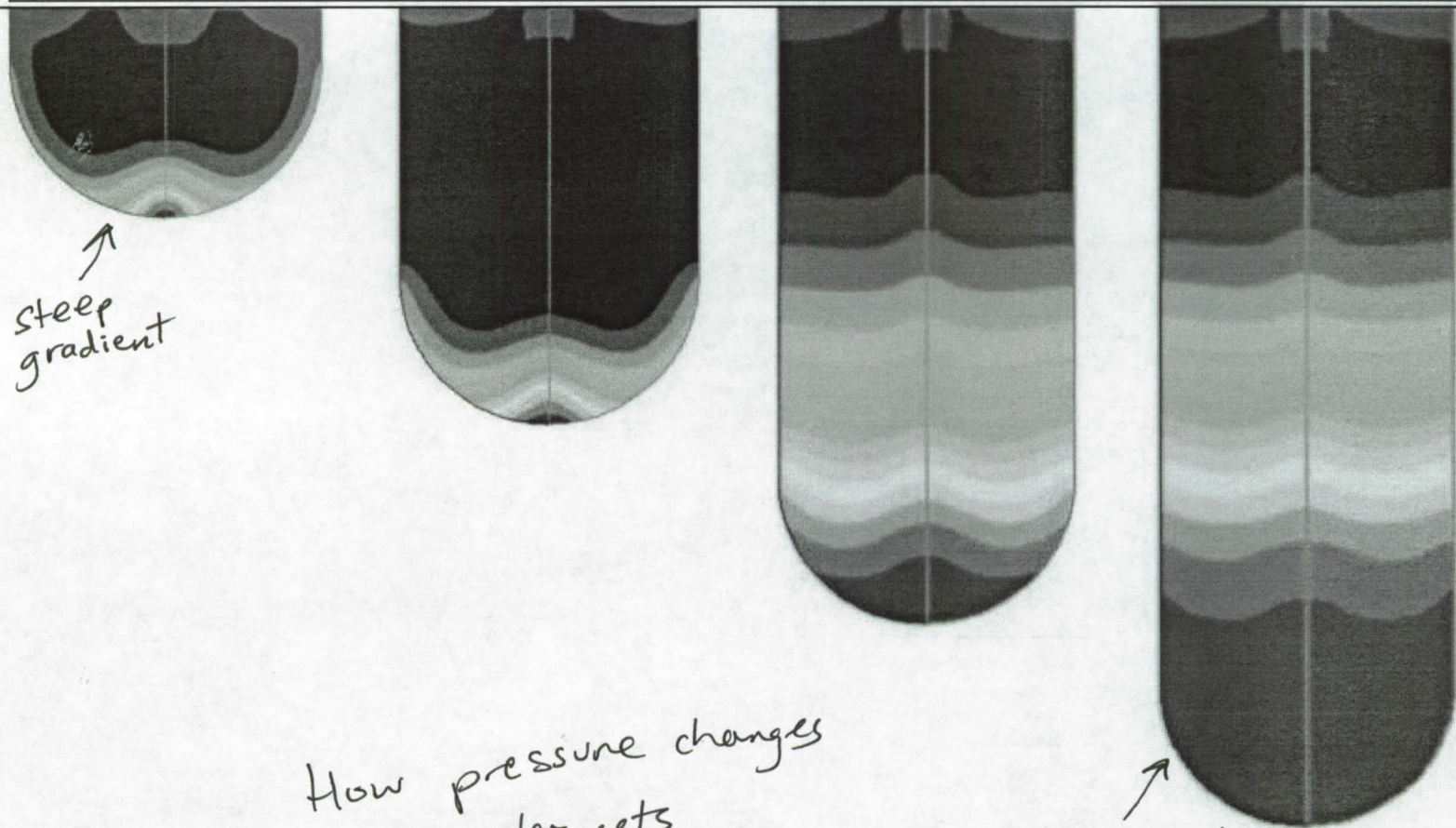
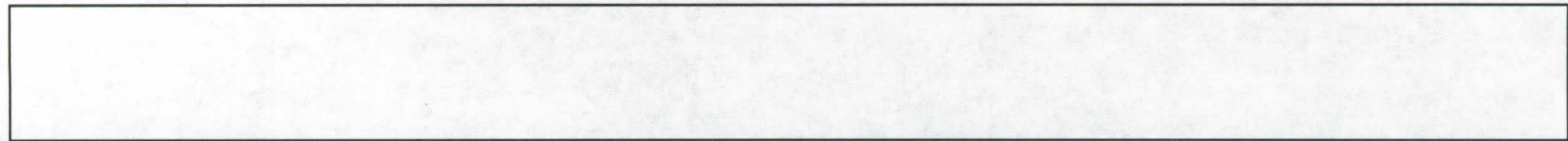
Simulation of flow velocity



Simulation of gas pressure
in crater



Simulation of gas pressure
between the sand grains

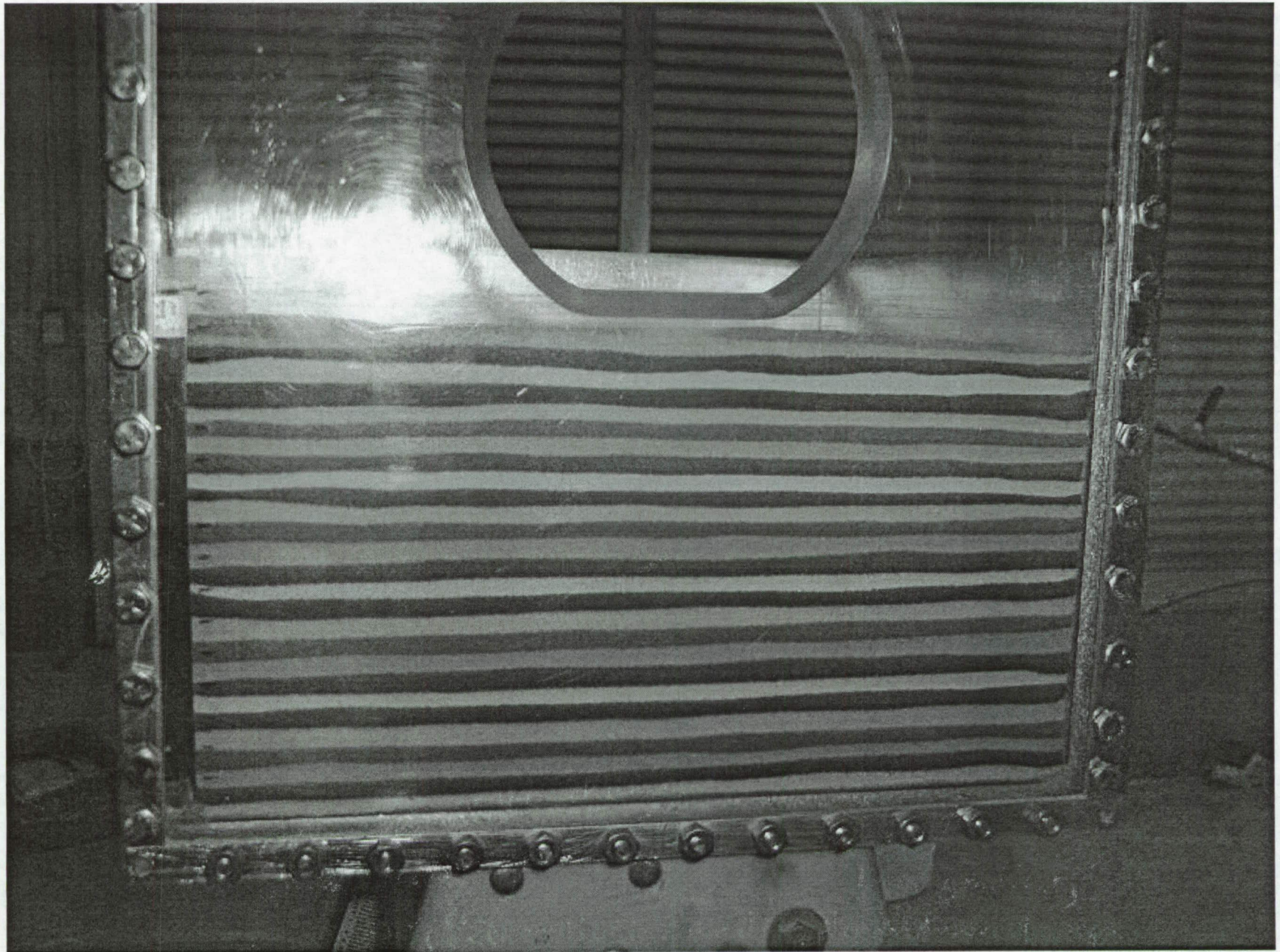


↑
steep
gradient

How pressure changes
when crater gets
deeper.

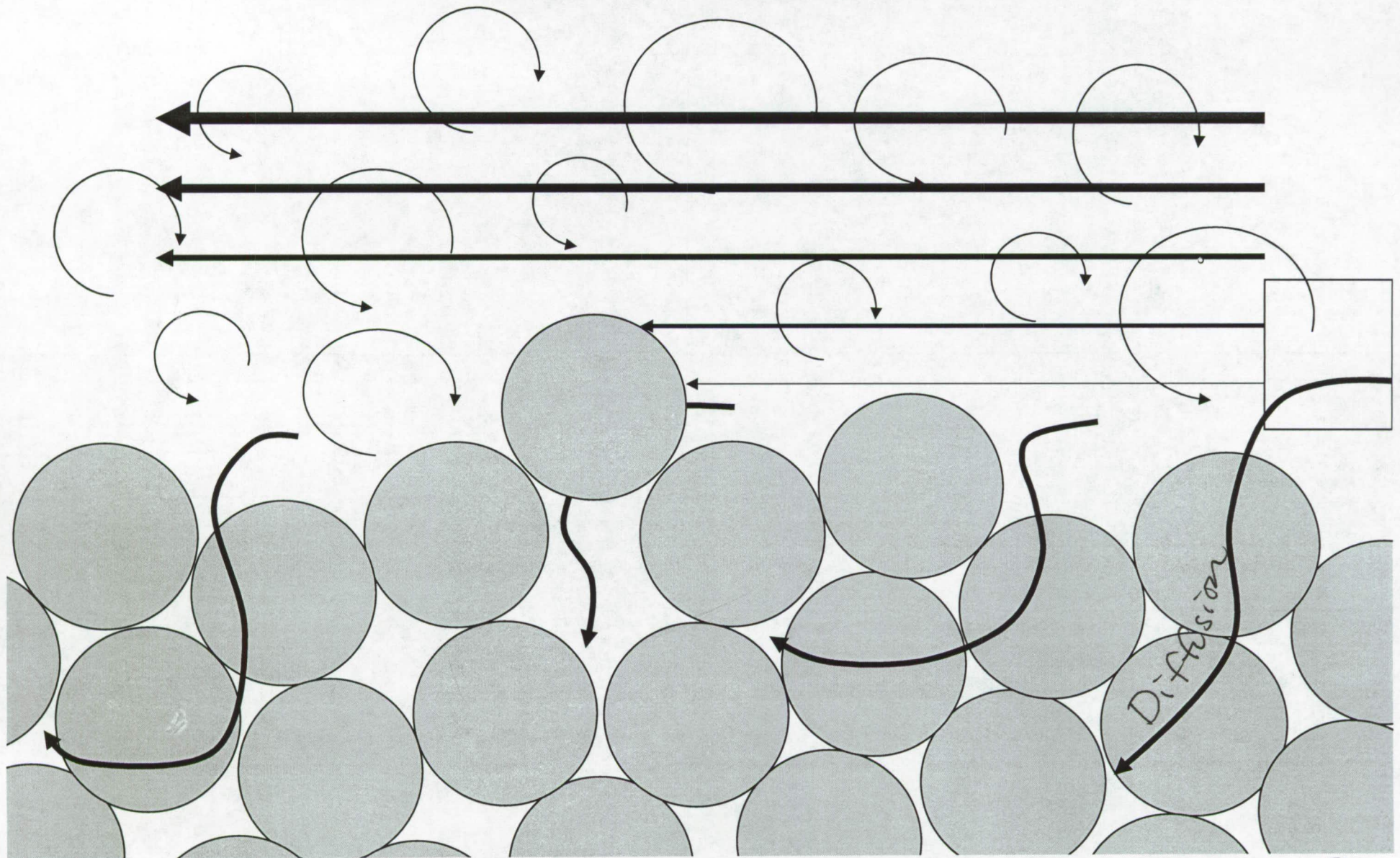
↑
Less gradient,
slows down & stops
crater growth

Movie of self-limiting cratering



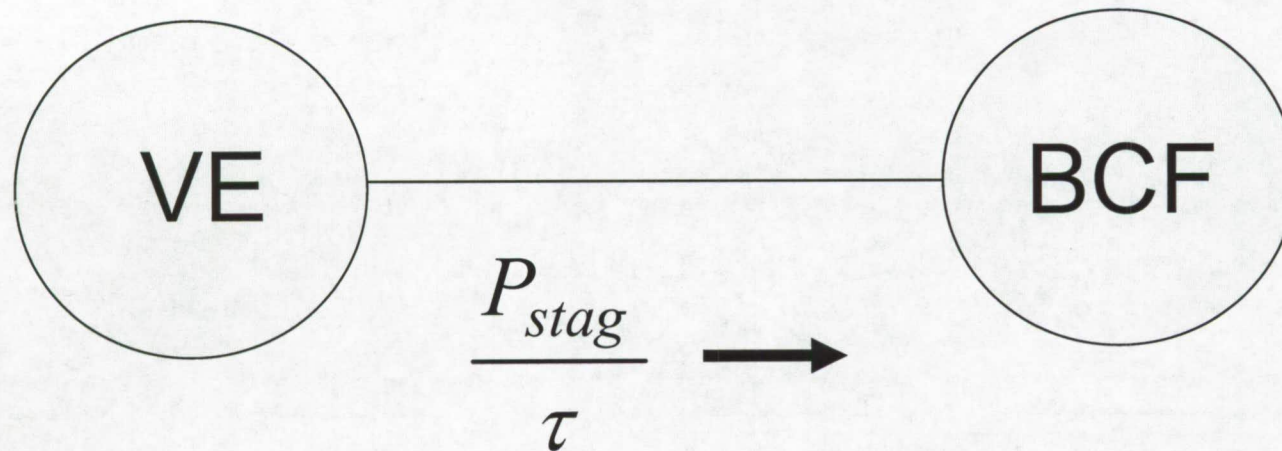
watch how crater self-limits its depth

Viscous Erosion



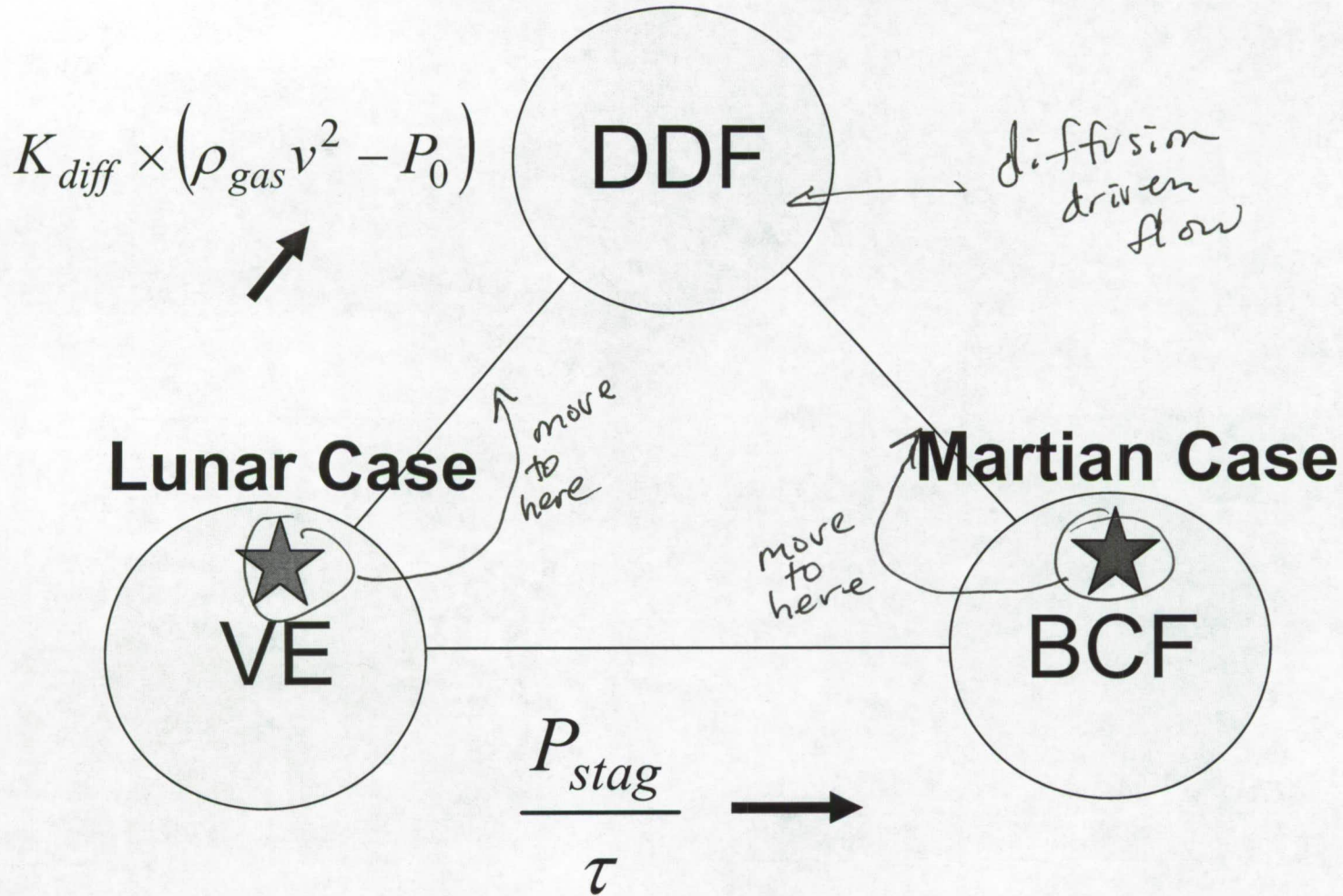
Now we can add a new erosion mechanism, Diffusion-Driven Flow

Paradigm ca. Apollo Program

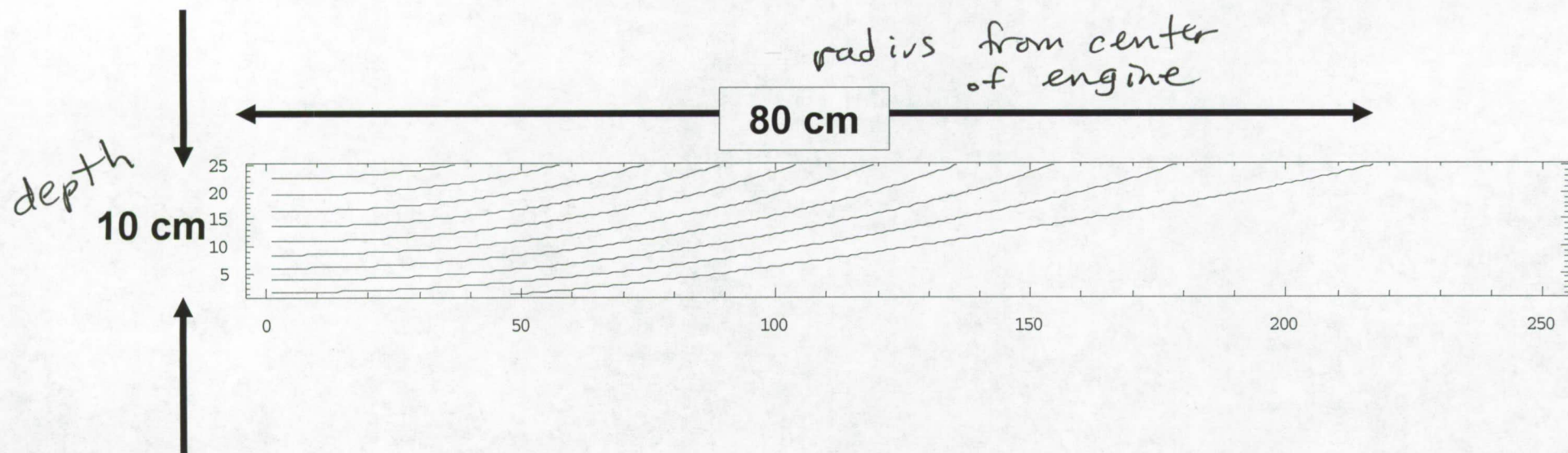


Old Paradigm

New Paradigm



New paradigm



Simulation of diffusion into soil beneath a lunar lander engine, using typical parameters but not for any specific spacecraft.